Introduction

- Highlight on performance of **lepton and photons**
  - Identification efficiencies/scale factors (ratio of data/MC efficiency)
  - Scale Factor used to “calibrate” simulation to match data
- **New results**
  - Updated muon reconstruction and identification
  - Displaced leptons reconstruction
  - Boosted di-τ reconstruction and identification
  - Merged ee reconstruction and identification
- Results from run II data (2015-2018)
- [Tracking performance](#) on Thursday by Mia
- [Flavour-tagging / Jet / Met performance](#) on Thursday by Jonathan
ATLAS Detector

- **Inner Detector, |\( \eta \)|< 2.5**
  - Silicon pixel and microstrip (SCT) and straw tubes (TRT)
  - 2T solenoid magnetic field

- **LAr Electromagnetic Calorimeter**

- **Scintillators and LAr for Hadronic Calorimeter**

- **Muon Spectrometer using trigger (RPC/TGC) and high-precision tracking chambers (MDT/CSC)**

- **Toroid magnetic field for Outer detector**
  - ~0.5T in the endcap, ~1T in the barrel
Electron and Photon Reconstruction

- Reconstruction for $|\eta|<2.5$ starts from **topo-clusters** in the calorimeters
- Clusters are matched with tracks within a Region-of-Interest (RoI)
  - Converted and unconverted photons distinguished based on conversion vertex and hits in Si layer
- **Superclusters** are formed and matched to tracks
- Final calibration and analysis object creation
- Different procedure for forward electrons
Electrons Identification
- Using information from electron track, transition radiation in TRT, lateral and longitudinal development of EM shower
- WPs tuned using $Z\rightarrow ee$ for $p_T > 15$ GeV and $J/\psi$ for $p_T < 15$ GeV
- Uncertainties at ±1% above 30 GeV
- Scale Factors within 5% from unity above 20 GeV

Photon Identification
- Cuts on calorimetric variables (shower shapes, deposited energy in the HCAL)
- MC shower shapes corrected with data-driven “fudge” factor
- Efficiency calculated in three samples (Inclusive photons, $Z\rightarrow l\bar{l}$, $Z\rightarrow ee$ events)
- SF compatible within uncertainties
- Delivered SFs combined using weighted average
- Uncertainties range between 12% to 0.5%
Calorimeter isolation $E_T^{\text{Cone}}$ computed using clusters whose barycenters lies within a cone centred around $e\gamma$ cluster

- Track isolation cone size $\Delta R$ decreases as function of electron $p_T$
- Three WPs with fixed requirements on calorimeter and track isolations
- Overall SFs are within 5% from the unity
Merged-ee Identification and Isolation

- $H\rightarrow ll\gamma (m_{ll}<30\text{GeV})$ interesting to probe BSM coupling modifications
- Merged ee defined as a topological cluster in the EM calorimeter associated to two opposite charged ID tracks
- Merged-ee energy calibrated as a converted photon with a 30 mm conversion radius
- Multivariate discriminator to separate $\gamma^*$ signals from jets or single electrons
- Efficiencies calculated with tag-and-probe using $Z\rightarrow ll\gamma$ decays
- SF within 0.9 and 1.1 with uncertainties between 2% and 9%

NEW!!

$|\eta^\gamma| < 0.8$

$0 < |\eta^\gamma| < 0.8$

$\sqrt{s} = 13\text{ TeV}, 139\text{ fb}^{-1}$

$\text{Merged ee isolation efficiency}$

$\text{Merged ee isolation efficiency}$

$\text{Efficiencies calculated with tag-and-probe using } Z\rightarrow ll\gamma$ decays

$\text{SF within 0.9 and 1.1 with uncertainties between 2\% and 9\%}$

arXiv:2103.10322
Muon Reconstruction

- Four complementary types of reconstructed muons: Combined, Segment-tagged, Stand-alone and Calorimeter-tagged muons
- Five reconstruction WPs, depending on the kinematics and desired purity
- Two methods to measure efficiency
  - Tag&Probe in the $|\eta|<2.5$ region (ID acceptance)
  - Double-ratio for $2.5<|\eta|<2.7$
- $Z\rightarrow\mu\mu$ and $J/\psi\rightarrow\mu\mu$ decays used to measure efficiency
Muon Identification

- Efficiencies from $J/\psi$ and Z decays compatible in overlap region
  - Large uncertainties at low pT due to larger background contamination
- Efficiency and SF stable after 10 GeV
- For $3 < p_T < 15$ GeV, SF measured with $J/\psi$ decays in the $(p_T, \eta)$ plane
- For $p_T > 15$ GeV, SF measured with Z decays in $(\eta, \Phi)$ plane

NEW!!

arXiv:2012.00578
Muon Identification

- Good agreement in Low-$p_T$ between Data/MC, except in $|\eta|>2.0$, $p_T<4$ GeV region
  - Faulty Cathode Strip Chambers (CSC) not modelled in simulation, lower segment-reconstruction efficiency in CSC relative to simulation for low-$p_T$ muons
- Above 10 GeV, overall agreement at 0.5% level
  - Some inefficiencies due to detector support structures or poorly aligned chambers
Muon Isolation

- Only $Z$ decays with $p_T > 3$ GeV probes considered
- Six working points
- SF measured as function of $p_T$ and $\Delta R$ from the nearest hadronic jet
- Agreement at per-mille level for $p_T > 10$ GeV.
- Increasing uncertainty at low $p_T$ and near or close to jets, due to the MC modelling uncertainty (Pythia vs Sherpa)

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arXiv:2012.00578
Prompt lepton identification essential for several analysis (e.g. ttH)

Non-prompt leptons are rejected using a BDT, taking as input the energy deposits and charged-particle tracks in a cone around the lepton direction

Prompt Muon (electron) Identification efficiency about 70% (60%) for $p_T$~10 GeV, plateauing at 98% (96%) at $p_T$ ~ 45 GeV for selected WP

Rejection factor against leptons from the decay of b hadrons is about 20

Scale Factor between 0.9 and 1.0
Displaced lepton reconstruction

- Displaced lepton reconstruction fundamental to explore several BSM models, e.g. GMSB SUSY
  - Displaced leptons with no visible decay vertex
- Using triggers without tracking information
- Standard tracking: reconstructs tracks with $|d_0| < 10\text{mm}$, then adds tracks with $|d_0| < 300\text{mm}$ with remaining hits
- Extended tracking: matching to EM cluster or MS segments

Modified ID algorithm removes requirements on $|d_0|$ and matched hits
- Clear improvement w.r.t. to standard algorithm

NEW!!

**Tau Reconstruction**

- Tau seeded from anti-kt4 jets
- BDT track classification
- Particle flow: $\pi^0$ built from EM clusters subtracting EM energy from charged pions
- BDT to better separate tau decay modes
- Boosted regression tree (BRT) to calibrate tau energy

**RNN Algorithm**

- Recurrent neural networks discriminating jets
- Input variables related to
  - High-level: $\tau$ lifetime, isolation, energy fractions, ...
  - Low-level: tracks and clusters
Boosted di-\(\tau\) reconstruction and identification

- Boosted di-\(\tau\) fail standard reconstruction procedure because of small \(\Delta R\) (<0.4)
- Seeding with untrimmed large-radius jets \((p_T>300\text{ GeV})\), having at least two sub-jets
- Leading sub-jets construct di-\(\tau\) system
  - Tracks matched to sub-jets if \(\Delta R<0.2\)
- Clear improvement in efficiency w.r.t. standard resolved \(\tau\) reconstruction

NEW!!

\[ \text{ATLAS Simulation} \]
\[ X \rightarrow HH \rightarrow b\bar{b}\tau_n\tau_n \]
\[ \sqrt{s} = 13\text{ TeV}, \ m_H = 2\text{ TeV} \]
\[ p_T(\tau_{vis}) > 10\text{ GeV}, p_T(\text{di-}\tau_{vis}) > 300\text{ GeV} \]
Conclusions

- ATLAS performance for leptons and photons meet requirements for run II conditions
- Several activities carried own by the performance and analysis groups
  - New low-mass merged-ee reconstruction and identification
  - Full run-II muon reconstruction and identification performance
  - Displaced lepton reconstruction
  - Boosted di-tau reconstruction and identification
- Preparation for run-3 ongoing
- For further discussion: [https://cern.zoom.us/j/61590132304?pwd=SU9UT1Q5Y1B3RnUzOHNGWXVjRUJTdz09](https://cern.zoom.us/j/61590132304?pwd=SU9UT1Q5Y1B3RnUzOHNGWXVjRUJTdz09)
References

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3. Evidence for Higgs boson decays to a low-mass dilepton system and a photon in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector
4. Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s}=13$ TeV
5. Search for displaced leptons in $\sqrt{s}=13$ TeV pp collisions with the ATLAS detector
7. Identification of hadronic tau lepton decays using neural networks in the ATLAS experiment
8. Measurement of the tau lepton reconstruction and identification performance in the ATLAS experiment using pp collisions at $\sqrt{s}=13$ TeV
9. Reconstruction and identification of boosted di-$\tau$ systems in a search for Higgs boson pairs using 13 TeV proton–proton collision data in ATLAS
Thank you for listening, any questions?

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Electron and Photon Energy Calibration

- $Z\rightarrow ee$ events used to calibrate energy scale and resolution
- Scale uncertainties 0.04% to 0.2%
Electron and Photon Superclusters

All $e^\pm, \gamma$:
Add all clusters within $3 \times 5$ window around seed cluster.

Electrons only:
Seed, secondary cluster match the same track.

Converted photons only:
Add topo-clusters that have the same conversion vertex matched as the seed cluster.
Add topo-clusters with a track match that is part of the conversion vertex matched to the seed cluster.
Tau Identification

- Scale Factors measured with tag and probe method
- Considering $Z \rightarrow \tau_\mu \tau_{\text{had}}$ decays, using $\tau_\mu$ as tag
- Three Working Points corresponding to different target efficiency values
- SFs around 1 with a max 5% uncertainty
Electron and Photon Reconstruction efficiency

![Graph showing reconstruction efficiency vs. true energy for different ATLAS simulation scenarios.](image)

**ATLAS Simulation**
- Cluster
- Track
- Cluster and track
- Electron candidate

![Graph](image)

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High-$p_T$ muon identification

ATLAS
$\sqrt{s} = 13$ TeV, 139 fb$^{-1}$

$H_{\text{igh-}p_T\text{-muons}}$
$p_T > 30$ GeV

Data Efficiency [%] vs $\eta$

Scale Factor [%] vs $\eta$

arXiv:2012.00578
Tau Energy Calibration

- calibrated for pT(gen) with boosted regression tree (BRT)
  - interpolated, calo & particle-flow pT
  - calorimeter-related variables $N_{PV}$, $N_{track}$, $N_{\pi 0}$, ...
- resolution ~6%
- energy scale in MC ~1-3%
Tag & Probe Method

- Considering sample with dimuon pairs (Z or J/ψ)
- Tag muon required stringent identification criteria and triggers the event selection
- Probe used to test efficiency of a particular WP X

\[ \epsilon(X|P) = \frac{N_X^{\text{Probe}}}{N_X^{\text{All Probe}}} \]

arXiv:2012.00578
Muon Total Identification Efficiency

- Overall reconstruction and identification efficiency measured in data with $Z \rightarrow \mu\mu$ and $J/\psi \rightarrow \mu\mu$ decays for prompt muons with $p_T > 3$ GeV.
- The total identification efficiency for satisfying simultaneously the Medium, PflowLoose isolation and vertex association criteria (black line) is shown together with its separate components (coloured markers).
Muon Momentum Calibration

- A set of corrections is applied to the simulated muon moment to improve data/MC agreement
- Correction parameters extracted using the $J/\psi \to \mu\mu$ and $Z \to \mu\mu$ candidates with two oppositely charged CB Medium muons
- Improved Data/MC agreement. Uncertainties between 5% (Z) and 20% ($J/\psi$)

Electron Identification

- Three Working Points (WP) constructed using a likelihood discriminant selection
  - Variables include information from electron track, transition radiation in TRT, lateral and longitudinal development of EM shower
  - WPs tuned using $Z \rightarrow ee$ for $p_T > 15$ GeV and $J/\psi$ for $p_T < 15$ GeV
- Uncertainties at ±1% above 30 GeV
- Scale Factors within 5% from unity above 20 GeV
Electron Isolation

- **Calorimeter isolation** $E_T^{Cone}$ computed using clusters whose barycenters lies within a cone centred around $e\gamma$ cluster
- **Track isolation cone size** $\Delta R$ decreases as function of electron $p_T$
- Three WPs
- SFs ranges between 1-5% from unity

*ATLAS*
\[
\sqrt{s} = 13 \text{ TeV}, \; 44.3 \text{ fb}^{-1}
\]
Electrons, Medium ID
Photon Identification

- Photon candidates identified applying cuts on calorimetric variables (shower shapes, deposited energy in the HCAL)
- MC shower shapes corrected with data-driven “fudge” factor
- Three methods for photon identification efficiency
  - Inclusive photons, $Z\rightarrow ll\gamma$, $Z\rightarrow ee$ events
  - SF compatible within uncertainties
  - Delivered SFs combined using weighted average
  - Uncertainties range between 12% to 0.5%
Photon Isolation

- Three WPs with fixed requirements on calorimeter and track isolations
- Measured using $Z \rightarrow l \ell \gamma$ radiative decays and inclusive photons
- Overall SFs are within 5% from the unity